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BRAIN ACTUATED CONTROL OF A ROLL AXIS TRACKING SIMULATOR (U)

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

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FOR THE COMMANDER

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Investigations of steady-state evoked electroencephalographic potentials as indicators of mental workload have led to successful implementation of a closed-loop paradigm allowing the possibility of brain actuated control. A three-channel Lock-in Amplifier System (LAS-3) was used to obtain an artifact-free brain resonance signal at a specified frequency. Lead-lag compensation of the LAS-3 gain signal was investigated as a means to produce the brain actuated control. A Roll Axis Tracking Simulator (RATS) was used as a kinesthetically salient control/feedback environment. This paper discusses efforts to make use of a methodology for using the derivative of selected brain resonances as a control signal in the kinesthetically salient environment of the RATS.

Visually evoked response, loop closure, electroencephalographic signals

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ABSTRACT

Investigations of steady-state evoked EEG potentials as indicators of mental workload have led to successful implementation of a closed-loop paradigm allowing the possibility of brain actuated control. A three channel Lock-in Amplifier System (LAS-3) was used to obtain an artifact free brain resonance signal at a specified frequency. Lead-lag compensation of the LAS-3 gain signal was investigated as a means to produce the brain actuated control. A Roll Axis Tracking Simulator (RATS) was used as a kinesthetically salient control/feedback environment. This paper discusses efforts to make use of a methodology for using the derivative of selected brain resonances as a control signal in the kinesthetically salient environment of the RATS.

1. INTRODUCTION

Investigations of steady-state evoked potentials as indicators of mental workload have led to successful implementation of a closed-loop paradigm allowing the possibility of brain actuated control (Junker et. al., 1987). Hardware has been developed which permits timely and frequency specific feedback to human operators of the resonances embedded in their ongoing EEG. Control of these resonances has been demonstrated by all subjects tested. These efforts have led to an ongoing research program designed to quantify mental resource allocation during performance of the Criterion Task Set (Shingledecker, 1984). In addition, a system which rejects broadband noise and nonspecific broadband control artifacts has been developed.

While engaged in the above research an interest to explore two new questions developed. The first addresses the feasibility of developing a more sensory compelling feedback environment. This need arises from observations that Brain Actuated Control (BAC) success is sensitive to the salient nature of the feedback cues provided to achieve loop closure. The more involving the loop closure cues are, the more effective the training of BAC appears to be. This increase in effectiveness should yield a corresponding decrease in the training time necessary to learn BAC. Therefore it is hypothesized that kinesthetic cues, in this case acceleration cues resulting from control of a motion environment, would enhance the learning of BAC.

Secondly, the question of what the BAC signal represents in a control context needs to be addressed. In other words, how should the process of controlling one's EEG resonance be utilized for machine control? Previous experimentation has revealed that subjects are better at controlling change of resonance (increase/decrease) rather than holding constant resonance levels (Junker, Schnurer, Ingle, Downey, 1988). This mode of control (i.e. undershoot and overshoot) can be observed when subjects are engaged in tracking tasks involving the control of a lagging or sluggish system. From our previous results we concluded that the BAC signal was lagging the subject's 'desired control' at the neural level resulting in the inability to keep the BAC at a constant level. This is reasonable to hypothesize since there is an inherent integration or filtering effect from the scalp and the equipment used to produce the present BAC signal. Lead compensation, in the form of differentiation, of the BAC signal should reduce this problem. Thus the lead compensated EEG resonance signal was used as the BAC and as feedback to the subjects.

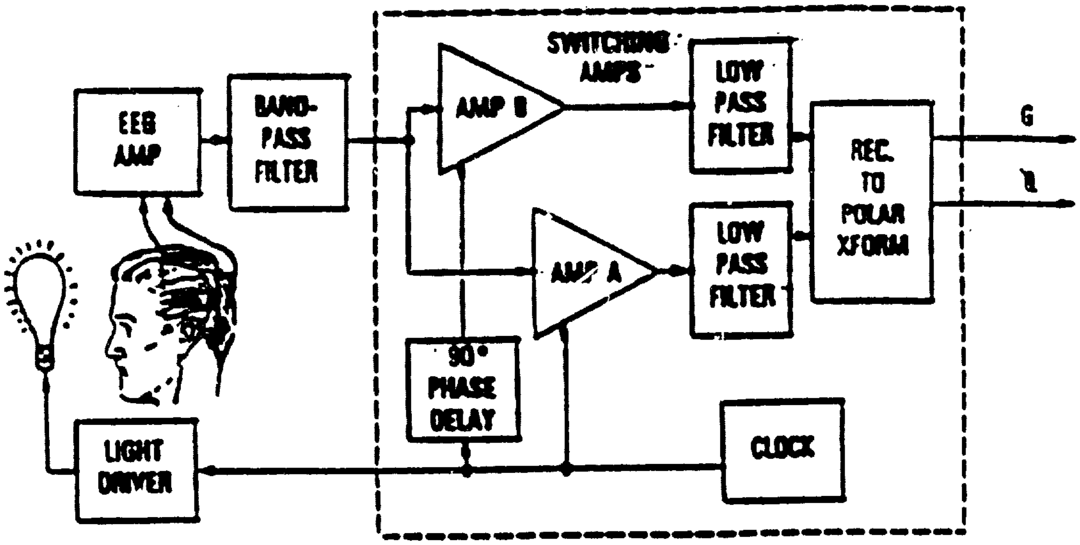

Figure 2.1 Lock-in Amplifier System

2. METHODOLOGY

2.1 Loop-Closure and EEG Detection Apparatus

Equipment development proceeded along the following lines. A three channel Lock-in Amplifier System (LAS-3), shown in figure 2.1, was created to obtain an artifact free brain resonance signal at a specified frequency. The LAS-3 is an analog device which provides near real-time frequency domain gain and phase information for a signal (EEG in this case) at a reference frequency. Lead-Lag compensation of the LAS-3 gain signal was added as a means to produce a responsive brain actuated control signal.

Gold cup surface electrodes, manufactured by Grass, are placed on the scalp over the occipital cortex O1-O2 and mastoid process for ground (according to the 10-20 International system). In order to achieve good electrical contact, the scalp is mildly abraded by brisk rubbing with an alcohol soaked gauze pad. A nonabrasive electrode paste, Grass EC2 Electrode Cream, is put on the cleansed area, with electrode affixed to the subjects' scalps with the same electrode cream. No adverse reactions to these procedures or materials have been encountered in our laboratory.

2.2 Control/Feedback Environment

A Roll Axis Tracking Simulator (RATS) is used in a kinesthetically salient control paradigm. Within the RATS, subjects employ a manually operated actuating mechanism as a means of engaging/disengaging their brain actuated control. The direction of the BAC input is indicated with a horizontal light bar (zero input referenced to center) and a left/right audio feedback tone. The interior layout of the RATS cab is illustrated in Figure 2.2. The evoking stimulus is provided by two fluorescent tubes mounted within lexan tubes. A video monitor provides roll position and roll velocity cues. As indicated in Figure 2.2 the light bar and audio displays are intended to provide cues equivalent to those that would normally be available kinesthetically from manipulation of a manual controller.

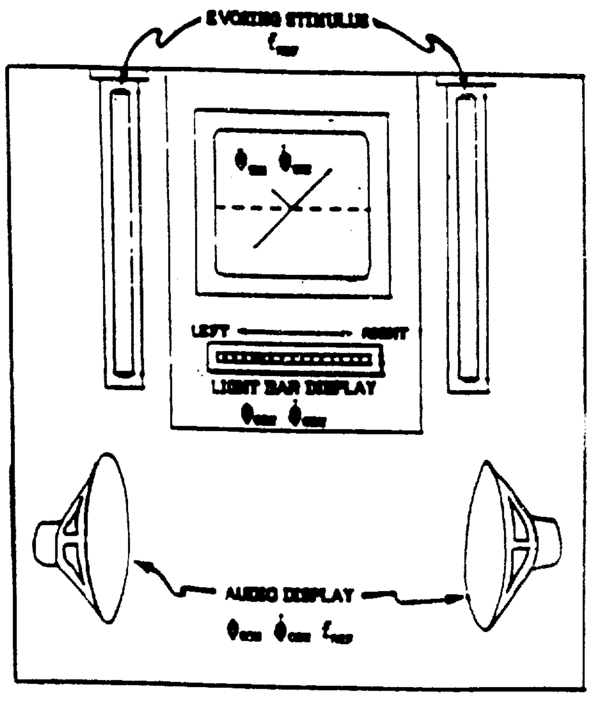

Figure 2.2 Interior Layout of RATS cabin

2.3 Experimental Plan

Closed-loop tracking with visual only, visual and kinesthetic, and kinesthetic only cues is performed. In each case roll disturbance regulation is added. A digitally generated low frequency sum-of-sine waves is used as the disturbance input. The resulting closed-loop block diagram for this system is illustrated in Figure 2.3.

Data is collected which is frequency coupled to the sum-of-sines disturbance. This allows computation of various system transfer functions. Performance scores and system transfer functions provide a basis for evaluation of the LAS-3/RATS equipment (bandwidth, stability) and human BAC capabilities.

Subjects are exposed to static conditions or nonhazardous angular motion on the RATS while observing a CRT display and performing BAC tracking control. During experimental sessions in the RATS subjects are secured with a five point seat belt and shoulder harness. The experimenter is in continuous contact with the subject at all times through an intercom which has a live subject mike.

The experiment is divided into three phases: Phase I-Subject Introduction to BAC and RATS control; Phase II Training With BAC and RATS; and Phase III- Data collection During BAC Closed-Loop Disturbance Regulation.

Phase I. The basis of this phase is to introduce subjects to the experimental equipment and the concept of brain actuated control. At first subjects have the opportunity to control the RATS with a manual controller to become comfortable with the motion capabilities of the RATS. Subjects are allowed to select a resonance frequency at which they will accomplish BAC (between 13Hz and 20Hz). At this time the experimenter is able to characterize the subject's evoked EEG response. This phase normally takes two experimental sessions to complete.

Phase II. The results from the first phase are used to set parameters for the second phase in which subjects train in BAC on the RATS. Initially, training consists of simply learning to control the RATS with no external disturbance. AS subjects become comfortable with BAC control a simplified disturbance is added to the closed-loop system. As subjects become proficient at disturbance regulation using BAC, introduction of a sum-of-sines disturbance occurs marking the beginning of Phase III. Phase II training requires approximately 7 experimental sessions for each subject tested.

Phase III. This phase involves data collection and training with the computer generated sum-of-sines disturbance input. Data collection continues until performance scores (RMS error) reach consistent levels. Three conditions are tested: static tracking with visual cues using BAC, motion tracking with visual cues using BAC, and motion tracking with no visual cues using BAC.

Data analysis consists of tabulation and analysis of RMS error scores for quantifying learning rates and effectiveness of accomplishing closed-loop control. Frequency analysis of disturbance regulation data provides transfer functions of human and machine systems. From these transfer functions effectiveness of BAC control relative to current manual control is evaluated.

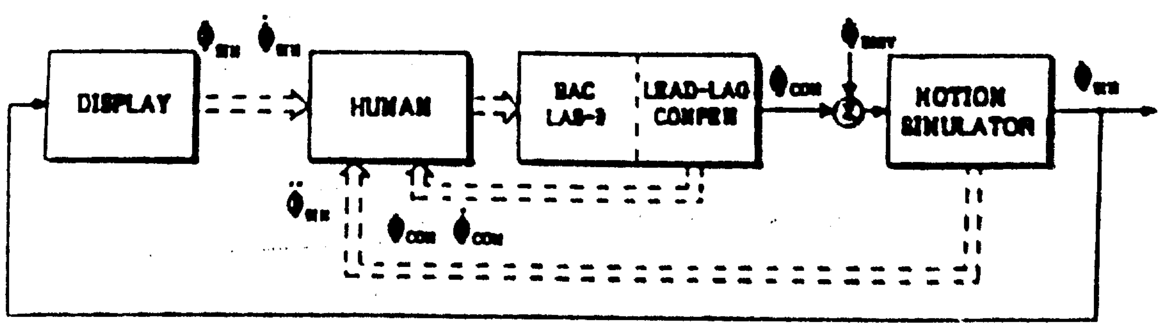

Figure 2.3 Closed-loop RATS/LAS-3 system

3. PRELIMINARY RESULTS AND DISCUSSION

At present the pilot study is in its initial data collection stage. However, even at this preliminary stage participants subjectively claim they feel the onset of control in the kinesthetically salient environment (RATS) at an earlier point than subjects who trained in a totally static mode. This, if true, could be from two possible sources. First, the RATS provides a subject with feedback imperative of a much higher magnitude than can be found under static conditions. Including a subject's kinesthetic sense in a feedback loop allows an individual to respond and compensate for his dynamic environment in much the same way people learn to regain their equilibrium and 'right' themselves after stumbling. The second cause could be the effectiveness of lead-lag compensation of the physiological measure (specific frequency EEG). This lead-lag compensation results in a bandwidth increase of the measure such that feedback of the sensed physiological signal comes fast enough in terms of RATS responsiveness.

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